Journal of Outdoor Recreation and Tourism 38 (2022) 100475

Contents lists available at ScienceDirect

Journal of Outdoor Recreation and Tourism

journal homepage: www.elsevier.com/locate/jort

Dysfunctional information feedbacks cause the emergence of management panaceas in social-ecological systems: The case of fish stocking in inland recreational fisheries

Robert Arlinghaus [a,b,*], Carsten Riepe [a], Sebastian Theis [c], Thilo Pagel [d,a], Marie Fujitani [e,f]

[a] Department of Biology and Ecology of Fishes, Leibniz Institute of Freshwater Ecology and Inland Fisheries, Germany
[b] Division of Integrative Fisheries Management, Humboldt-Universität zu Berlin, Germany
[c] Department of Renewable Resources, University of Alberta, Canada
[d] Institute of Inland Fisheries, Potsdam-Sacrow, Germany
[e] Department of Social Sciences, Leibniz Centre for Tropical Marine Research, Germany
[f] Institute for Geography, University of Bremen, Germany

ARTICLE INFO

Keywords:
Social-ecological systems
Positive feedbacks
Recreational fisheries
Governance
Transdisciplinarity
Information flow

ABSTRACT

Social-ecological systems are characterized by interconnections between social (e.g., angler communities) and ecological systems (e.g., fish populations in lakes and rivers). One means by which human actions feedback on ecosystems is through management actions, some of which are controversial due to the possible downsides for biodiversity and ecosystem functioning. In complex systems, sub-optimal management strategies may become entrenched. In such cases, leverage points must be identified to escape undesirable stable states. Based on a review of published and grey literature about the management practice of fish stocking in German inland recreational fisheries, we describe key pathways characterizing social-ecological interactions and resulting outcomes. The pathways we review suggest that missing or dysfunctional information feedbacks predispose privately governed fisheries-management systems typical of Germany to develop stocking as a panacea in operational management. Similar outcomes are likely in open access recreational fisheries. Three key feedback cycles reinforce each other to maintain stocking in the manager's toolbox. The first is that the lack of dedicated monitoring in many fisheries and ignorance of research results breaks a feedback signal from the management measure of stocking to the evaluation of outcomes. The lack of ability of those involved in stocking to conclusively learn when stocking works and when it fails to deliver additive effects reinforces personal norms by managers and anglers that stocking may be necessary to sustain fisheries. A related second feedback is that stocking may increase catch rates in the short-term, which increases angler expectations for catch and stocking as a safeguard of the catch, in turn fostering linear cause-and-effect mental models and the emergence of a pro-stocking social norm among anglers. A third key feedback is among hatchery operators and fisheries managers in fishing clubs, where hatchery operators are often key informants about stocking practices while concurrently having commercial interests to sell fish for stocking. This creates economic incentives that perpetuate stocking. The amount of resource investments by angler communities through stocking is additionally fostered and maintained by monetary resource availability, size and type of ecosystem that is managed and governance processes as well as political inertia. Thus, the maintenance of stocking as a panacea is intimately linked to a range of psychological, social, economic and governance drivers. We use our case study to illustrate how information-related feedback loops can trap natural resource management strategies into a suboptimal basin of attraction, and provide recommendations on leverage points to possibly break these loops. Collaborative active adaptive management of natural resources and reducing the temptation to rely on economic incentives by hatcheries may be needed to introduce possibilities for learning and thereby avoid the entrenchment of stocking and related activities as a panacea. The lessons learned around stocking are applicable to a range of social-ecological issues in recreation and planning whenever feedback flows of information are critical to direct management and when these flows are either distorted by disinformation, wrong incentives or not present at all.

* Corresponding author. Department of Biology and Ecology of Fishes, Leibniz Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin, Germany.
E-mail address: arlinghaus@igb-berlin.de (R. Arlinghaus).

https://doi.org/10.1016/j.jort.2021.100475
Received 16 April 2021; Received in revised form 22 September 2021; Accepted 6 December 2021
Available online 17 February 2022

Management Implications: The study has several implications for fisheries and natural resource management:

- Establishment of regular monitoring systems that are trusted by stakeholder can be recommended and is key to break dysfunctional information feedbacks and move social-ecological systems, such as recreational fisheries, on more sustainable trajectories.
- Changing fish stocking under private fishing right systems can happen either through bottom-up approaches based on co-production of knowledge and using principles of adaptive management or from the top-down by implementing hard constraints on the possibility for self-organized stocking policies.
- The former strategy will be more time-consuming and may fail in some situations, but is likely to create less conflicts and more durable outcomes from a social perspective.
- Alternative to fish stocking, such as improvement of habitats or harvest constraints, should be considered whenever feasible.

1. Introduction

Recreational fisheries are examples of strongly coupled social-ecological systems (SESs) (Carpenter & Brock, 2004; Hunt et al., 2013). Key characteristics of such systems are behaviour-based feedbacks between social and ecological compartments, the flow of benefits from the ecological to the social system motivating actions and interventions by the social on the ecological system, the presence of cross-scale interactions (e.g., regionally mobile anglers linking separate lakes and rivers), and non-linearities and heterogeneities (e.g., among ecosystems, populations or individual resource users) (reviewed in Ward et al., 2016; Arlinghaus et al., 2017; Camp et al., 2020). Combined, these issues create path-dependencies, shape opportunities for selection, and adaptation and result in difficult predictability and possibly regime shifts where the system becomes trapped in an undesired state (Camp et al., 2020; Carpenter & Brock, 2004; Carpenter et al., 2017; Pope et al., 2014).

Recreational fisheries are characterized by direct interactions between humans and nature through the use of renewable natural resources and their active management. The use of fish by anglers can involve consumptive (e.g., catch and harvest, Cooke et al., 2018) as well as non-consumptive interactions (e.g., voluntary catch-and-release, Sass & Shaw, 2020). The tight feedbacks between humans and natural systems renders recreational fisheries an empirically tractable model case of SESs. Although at first glance a micro-scale policy issue, recreational fisheries exist as a network of overlapping social-ecological systems that connect the landscape and can have macro-level effects (e.g., spread of invasive species across continents, Davis & Darling, 2017). Recreational fisheries and recreational anglers display great diversity in biogeographical characteristics (e.g., types of ecosystems), behaviours, behavioural determinants (e.g., values, beliefs and attitudes), governance structures (e.g., type of angler associations) and policies at the landscape and socio-structural levels (Arlinghaus et al., 2017, Hunt et al. in press). This renders the SES of recreational fisheries an apt case for learning more generally about how SES unfold and function over time (Brock & Carpenter, 2007; Biggs et al., 2009; Horan et al., 2011; Pope et al., 2014). Importantly, anglers in many areas of the world are not only consumers of wild fishes, but also engage directly in habitat and stock management or fund such activities (Fig. 1, Loomis & Fix, 1998, Daedlow et al., 2011; Tufts et al., 2015; Sass et al., 2017). This is also the case in central Europe where fishing rights are private property and often held by local angler communities organized in clubs or associations (Arlinghaus, 2006; Daedlow et al., 2011; Eden & Bear, 2011). By studying how the population of self-organized angler communities (e.g., angling clubs) interact with natural and man-made ecosystems it is possible to identify critical feedback loops that drive system trajectories (Arlinghaus et al., 2017; Biggs et al., 2009; Brock & Carpenter, 2007; Horan et al., 2011; Hunt et al., 2011; Solomon et al., 2020; Ward et al., 2016). The central purpose of SES research is to identify the conditions that produce sustainable outcomes in the face of feedback loops, cross-scale interactions, change and uncertainty (Carpenter et al., 2017; Hansen et al., 2015; Solomon et al., 2020). The present synthesis piece contributes an examination of such a complex system and illustrates the procedure followed to determine points to intervene in the system to foster more sustainable outcomes.

In recreational fisheries, humans interact with ecological systems through two basic means. First, anglers catch fish and affect wildlife and habitats through their presence at the waterside and through harvesting, voluntary catch-and-release and bycatch actions (Lewin et al., 2006; Sass & Shaw, 2020). Second, humans intervene through management in natural processes either to maintain or increase the benefit stream or to restore some previously existing, more desired state (Cowx, 1994; Arlinghaus, Lorenzen, et al., 2016; Sass et al., 2017). The case of recreational fisheries in Europe involves both (Lewin et al., 2006; Arlinghaus et al., 2017). One prominent means by which recreational fisheries attempt to maintain the flow of resource units (fish) or to restore some past state is the practice of fish stocking (Cowx, 1994; Lorenzen, 2014; Sass et al., 2017), defined as the release of hatchery-reared or wild-captured fish from a foreign ecosystem into a target ecosystem (Lorenzen et al., 2012). From a scientific perspective, fish stocking is advisable when a) the degree of natural recruitment is low, b) this constraint cannot be ameliorated in the short-term, c) when the local fishing pressure is high, and d) when alternative means to support the catch are either infeasible or not desired (Lorenzen, 2005; FAO 2012; Lorenzen et al., 2012; Arlinghaus, Lorenzen, et al., 2016; Camp et al., 2017; Sass et al., 2017; Johnston et al., 2018). Practically, fish stocking

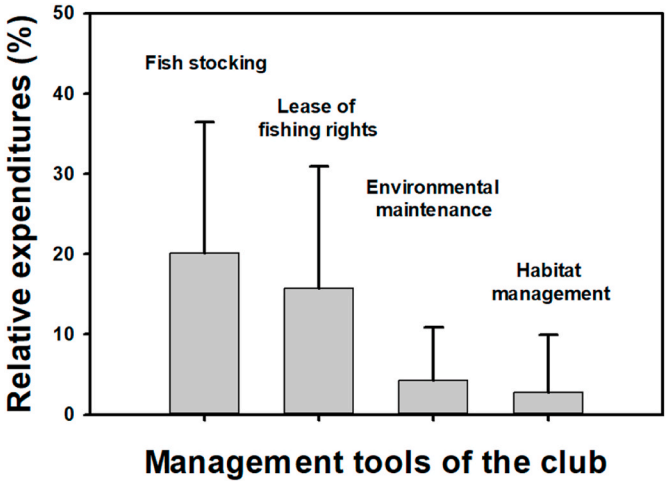

Fig. 1. Investment of the club budget (as a proportion of the total budget) into four kinds of activities within German angling clubs (N = 1222 respondents based on a random survey across Germany).

has become prominent in the 19th century after the development of artificial breeding and has become particularly widespread in freshwater fisheries (Cowx, 1994; Lorenzen, 2014; Lorenzen et al., 2012; Sass et al., 2017).

Fish stocking is a frequently used, and often abused, fisheries-management practice (Cowx, 1994; Sass et al., 2017). Although it can negatively affect biodiversity and ecosystem functioning when non-native or otherwise inappropriate genotypes or species are released into vulnerable ecosystems (Eby et al., 2006; Laikre et al., 2010), in other cases fish stocking can be a key resource to either conserve or restore threatened species or maintain and improve fisheries catch and yield (Cowx, 1994; Lorenzen et al., 2012; Arlinghaus et al., 2015). The practice makes intuitive sense to many stakeholders and thus enjoys strong support among freshwater anglers and managers (Loomis & Fix, 1998; Jackson et al., 2004; Arlinghaus & Mehner, 2005; von Lindern & Mosler, 2014; Taylor et al., 2017; Sass et al., 2017). At the same time, the practice is creating substantial controversy with conservationists due to the potential for irreversible biodiversity and ecosystem impacts (Waterstraat, 2002; Weibel & Wolf, 2002; Jackson et al., 2004; Eby et al., 2006; Laikre et al., 2010). For example, stocking may completely swamp local gene pools or lead to the spread of diseases or parasites (Lewin et al., 2006, Lorenzen, 2014, van Poorten et al., 2011; Bootsma et al., 2021). Ineffective stocking is also economically wasteful (Loomis & Fix, 1998; Johnston et al., 2018), and fixing issues such as the release of a non-native fish can be economically demanding or even impossible (Hickley & Chare, 2004; Johnson et al., 2009). Therefore, the current best practices dictate that stocking should only be conducted after properly evaluating the need and success probability of stocking, while minimizing negative conservation outcomes and cost/benefit ratios (Cowx, 1994; Arlinghaus, Lorenzen, et al., 2016; FAO 2012; Lorenzen et al., 2010; Sass et al., 2017). If one is to move fish stocking on sustainable trajectories, a better understanding of the human dimensions of stocking is needed because it is ultimately humans that design objectives, evaluate outcomes of alternative management approaches (Clark, 2006; Fujitani et al., 2018) and engage in stocking decisions (Jackson et al., 2004; Sass et al., 2017).

The objective of this paper is to summarize key pathways that contribute to the emergence and maintenance of stocking as a highly desired and often-used tool to manage recreational fisheries, particularly under private fishing right systems typical of central Europe (exemplified by Germany) where local angler communities are not only users but also legally entitled managers of local fisheries (Daedlow et al., 2011). To explain the emergence of fish stocking as a management panacea to achieve management objectives for fisheries (van Poorten et al., 2011; Sass et al., 2017), we outline the complexity of interactions and feedbacks that incentivize and control the stocking process. Stocking can be seen positively as a voluntary investment of civil society into natural resources (Fujitani et al., 2020) or as an undesired and ecologically risky practice that needs to be more sustainably managed and only used as a measure of last resort (Arlinghaus, Lorenzen, et al., 2016; FAO 2012; Sass et al., 2017) or not used at all (Waterstraat, 2002; Skeate et al., 2021; Weibel & Wolf, 2002). By delineating key social and ecological processes that lead to the emergence of an example of a management panacea (i.e., fish stocking), our contribution elucidates opportunities for successful interventions, provided policy makers are willing to be flexible in their management approaches. The emergence of stocking may then serve as an example case for a broader family of outcomes in coupled SESs in forestry, agriculture, hunting and other systems where humans are users and managers of natural resources. One key message of our and related work is that missing or dysfunctional information feedbacks and general political inertia may trap the system in undesired stable states. Although our paper is focused on Germany and private fishing rights system, the lessons learned also apply to open access governance systems typical for North America and other areas of the world.

2. Material and methods

2.1. Study system description

The system under review illustrate conditions in the Federal Republic of Germany. Here, fishing rights are private property linked to ownership of water bodies (Daedlow et al., 2011). Typically, the fishing rights of inland waters (lakes or river sections) are leased to individual fishers or angler communities organized in clubs or associations by water owners as the legal fishing rights holders (often the state, but also countries, enterprises or private people). The leaseholders of fishing rights, often local organizations like angling clubs or large(r) regional angler associations, in turn issue angling tickets to members of the clubs or associations. Thus, the legal entities are the fishing rights holders (which have a catch/harvest and management right/obligation), while the ordinary anglers are the permit holders (only carrying catch and harvesting rights).

In Germany, inland fishing laws are handled at the federal state-level (Bundesland), but general legal regulations of fisheries are fairly similarly structured across the country (Arlinghaus et al., 2015). In brief, the fishing rights holder (e.g., an angling club or a commercial fishing enterprise) is the only entitled human group who is allowed to catch wild-living fishes, while at the same time having management sovereignty as long as processes follow provisions as specified in the state-specific fishing or general nature conservation regulations. Fish that are released into natural or man-made ecosystems instantaneously become wild animals, but only those possessing fishing rights are allowed to catch them. Fishing rights holders are allowed to strengthen the minimum standards of state-level harvest regulations and other rules as stipulated in state-level fishing laws and by-laws (e.g., enhancing legal minimum-length limits), which also entails the right to engage in stocking, implement or enlarge protected zones or seasons or implement partial protection zones in the leased water bodies. The fishing rights holder (e.g., an angling club) may also engage in habitat enhancement although these practices are usually more difficult to be implemented than stocking as they might touch other legal bases than just the fisheries law (e.g., water law or nature protection law) (for a similar situation in the USA, see Sass et al., 2017). Stocking practices have to follow national level nature conservation and animal welfare and state-level fisheries laws. For example, nature conservation laws specify bans on releasing non-native species (Arlinghaus et al., 2015), and animal welfare laws motivate specific rules in terms of transport regulations. Otherwise, the stocking regulations indicating which sizes, species or densities to stock and from which origin the stocking material may originate are fairly liberal in Germany as the fishing laws specify only a few hard constraints (e.g., in some states only fish under the legal length limit are allowed to be stocked, Arlinghaus et al., 2015; Aas et al., 2018). Most stocking provisions are formulated as “ought” statements, e.g., that the genetic origin of the stocking material should match the recipient ecosystem, and enforcement by public authorities is very low (Arlinghaus et al., 2015).

The stocking material that is demanded by angling communities is mostly provided by commercially operated hatcheries or by commercial river and lake fisheries who culture or catch wild fish and sell them for stocking, often across biogeographic barriers (Arlinghaus et al., 2015), in contrast to national (Baer et al., 2007) and international scientific advice (Lorenzen, 2014; Miller & Kapuscinski, 2003; Fisch et al., 2015; Bootsma et al., 2021). The angling system in Germany is organized in a way that private anglers have to pass a 30-h training course and an angling examination to obtain a time-constrained harvesting right by the fishing rights holder. Although angling club membership is not mandatory, in many areas of Germany clubs or associations are the key leaseholders of fishing rights, and access specifically to small club waters is often bound to membership. The monitoring of catches as well as enforcement of local harvesting rules is typically self-organized in angling clubs or larger associations, and the managers of these clubs are

usually elected members of the clubs. Revenue by club members is invested into club activities, including stocking. Thus, the more money a club generates from its membership fees, the more resources are available to stocking (Fujitani et al., 2020). Sizes of angling clubs vary widely and are generally small in western Germany, while in the eastern federal states large angler associations are the fishing rights holders, with angling clubs having no decision power in terms of stocking (Daedlow et al., 2011). In both cases, the club or association, respectively, makes the decisions about stocking, while the ordinary club member pays into the budget and is not allowed to translocate or stock fish as a private person: the stocking right belongs to the fishing rights holder, not to the individual angling permit holder. Fisheries managers in angling clubs pass formal trainings in fisheries management that are often organized by large umbrella angler associations in collaboration with fisheries agencies (Fujitani et al., 2016), but typically are not academic fisheries biologists.

2.2. Empirical information base and synthesis procedure

The material summarized in this paper is structured around the findings of a six year research project about stocking in Germany that used qualitative and quantitative surveys among several thousand anglers and managers of local angling clubs in north-western Germany as well as adaptive stocking experiments in club waters to study the social, economic and ecological reasons underpinning stocking decision making (for a full report in German, see Arlinghaus et al., 2015, for text of key questionnaires, see supplementary material attached to Riepe et al., 2017, Fujitani et al., 2017 and Wegener, 2020, p. 207). Key insights that explain the stocking behaviour are summarized in the present synthesis paper. A methodological overview is provided in this section, for further details please see the cited sources. Sample selection for the quantitative surveys among both angling club heads (entire Germany, Riepe et al., 2017; Fujitani et al., 2020) and anglers (north-western Germany, Arlinghaus et al., 2014; Fujitani et al., 2016, 2017) was based on random sampling across the territory of Germany at the fisheries manager level and a random cluster sample of angling clubs in the federal state of Lower Saxony, respectively. The qualitative research followed a design that was tailored at maximizing the variation among the different clubs across four major states in East and West Germany, using a paired design (Ott, 2015). Quantitative angler surveys were conducted in 17 randomly selected angling clubs in north-western Germany as a case study (e.g., Mäurer, 2020, p. 126). The present work represents a review of the published work and also builds on several pieces of grey literature, mostly German reports (Arlinghaus et al., 2015) and master theses (Ott, 2015; Mäurer, 2020, p. 126; Wegener, 2020, p. 207) from which material is summarized here. The results are structured using a social-ecological system framework (Arlinghaus et al., 2017; McGinnis & Ostrom, 2014) where key interactions among components of the system (e.g., anglers-fish stock, anglers-managers, Ward et al., 2016) are first reviewed. Subsequently, we present a synthesis of the main influencing factors that we identified before we discuss our findings also in light of findings from open access recreational fisheries in other countries of the world. Our review is meant to be exhaustive of key German literature, but is only selected for the wider stocking literature.

3. Results

3.1. Fish stocking as a management panacea and its relevance relative to other management tools

We first establish the popularity and ubiquity of stocking as a management tool in German recreational fisheries, and then review the use of alternative management tools. This is done to show that stocking is indeed a panacea in fisheries management in Germany. A random survey of more than 1000 German angling clubs (tailored to the key decision maker about stocking in the clubs) revealed that in terms of average monetary investments about 20% of a club's available budget went into stocking. This investment was larger than investments into other activities, such as lease costs of fishing rights or costs of habitat enhancement (Fig. 1). When asked about the prevalence of stocking in the club's waters, 73% of all angling club heads and fisheries managers answered they used stocking annually in every water body under their control. In fact, together with daily bag limits and species-specific minimum-length limits, stocking was found to constitute the most temporally stable and consistently applied management tool used by German angling clubs (Fig. 2). This supports our assertion that in German recreational fisheries stocking is used as a widely applied silver bullet to cure a variety of perceived environmental and social problems (e.g., stock decline, angler dissatisfaction). By contrast, habitat enhancement activities were found to be the least prevalent management measures in German angling clubs (Fig. 2), used intensively by selected types of clubs only (Table 1). The situation mirrors conditions in the USA (Halverson, 2008; Sass et al., 2017).

Angling clubs were found to exhibit substantial heterogeneity in the application of different management tools. Cluster analysis of answers related to the prevalence of different management approaches across club waters revealed five different patterns of management activities in angling clubs in Germany (Table 1). The resulting five club types differed in the intensity with which they relied on harvest regulations (input and output controls) and habitat management. Yet, even the clubs that participated heavily in nature conservation actions involving habitat improvement also regularly and overwhelmingly stocked most lakes or rivers for which they held the fishing rights on an annual basis. Thus, despite ample variation among club management behaviours regarding the use of harvest regulations and habitat enhancement, we found little variation in stocking behaviour. That is, we found a strong consistency in using stocking on a regular basis in German recreational fisheries across different angling clubs. Detailed analysis of underlying mechanisms was necessary and followed to explain the emergence of stocking as a panacea, using qualitative and quantitative methods.

3.2. Key interactions in a complex adaptive social-ecological system

The previous section illustrated the central role of stocking to recreational-fisheries management in Germany. To understand and explain this phenomenon, one must find an entry point to examine a complex system and determine the mechanisms keeping stocking as a

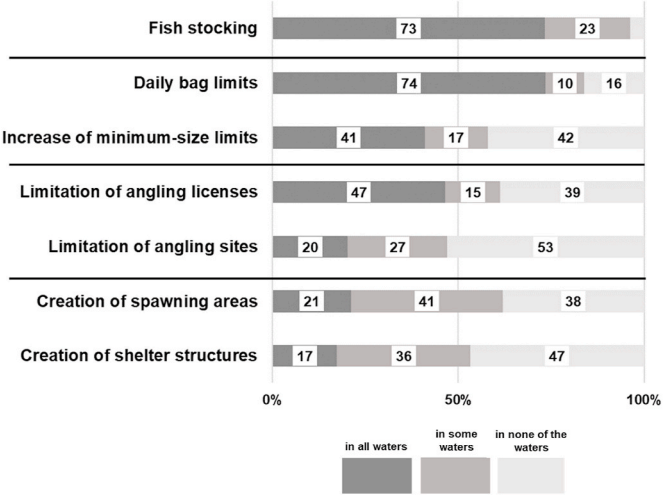

Fig. 2. Prevalence of various management tools (stocking, harvest regulations, habitat enhancement, differentiated by black lines) in the waters of German angling clubs. Data show the relative response frequency among N = 1222 responding angling clubs to the question to which degree the clubs used the indicated tool in all, some or in none of their waters on an annual basis.

Table 1
Relative frequencies (%) of management tools applied to most of the club's waters on a regular basis by five angling club types (N = 1.222).

Management tools	Passive clubs	Control clubs	Holistic control clubs	Habitat clubs	Do it all clubs
Annual bag limits	9%	54%	47%	70%	91%
Daily bag limits	3%	97%	87%	86%	92%
Limits on angling licences	14%	48%	48%	53%	86%
Limits on angling sites	10%	16%	12%	31%	80%
Increasing minimum-length limits over legal minimum standard for at least one species	14%	1%	98%	12%	91%
Increasing protected seasons above legal minimum standard for a least one species	5%	10%	57%	15%	83%
Installation of protected sites	11%	11%	32%	94%	90%
Creation of spawning sites	5%	2%	14%	92%	74%
Creation of fish refuges	5%	5%	10%	74%	68%
Large-scale habitat restoration (e.g., removal of migration barriers)	3%	3%	9%	26%	47%
Management of littoral zones	72%	97%	93%	87%	98%
Fish stocking	60%	84%	91%	88%	96%

management panacea. We did this by structuring our work using a social-ecological systems framework (Fujitani et al., 2020), which is intended to help diagnose sustainability in complex social-ecological systems by providing a common language and compartmentalization (Ostrom, 2009, McGinnis & Ostrom, 2014). Applying the framework, we identified relevant first-tier variables, that is, the governance systems, actors, resource units and resource systems. We then proceeded to evaluate the interactions between the variables in the system. The end result is conceptualized as a model in Fig. 3. In subsequent sections, we break down the pairwise interactions in this complex system, deconstructing the system to analyze individual factors driving the adoption of stocking as a management panacea. In the synthesis section, we bring these pieces back together and discuss the system as a whole to find the reasons for feedback loops, as well as places to target to potentially break them and change entrenched trajectories of management.

3.3. Angler-fish stock

German anglers derive substantial benefits from sufficiently high catch rates (Arlinghaus et al. 2014, 2020; Beardmore et al., 2015). Moreover, although some angler groups are able to discriminate between wild and hatchery fish and attach greater value to the catch of wild fish (Bryan, 1977, e.g., fly fishers targeting wild trout who differentiate wild fish from hatchery trout by the lack of fin erosions), most German anglers target species (e.g., pike, *Esox lucius*, eel, *Anguilla anguilla* or perch, *Perca fluviatilis*) that cannot be easily discriminated in the catch as naturally spawned or stocked. Indeed, at the population level and on average, German anglers were found to show no distinct preference for wild over stocked fishes in the catch (Arlinghaus et al., 2014). Moreover, graphical mental model exercises to assess ecological understanding of anglers in a cause-and-effect manner revealed a predominantly linear ecological thinking regarding the influence of fish

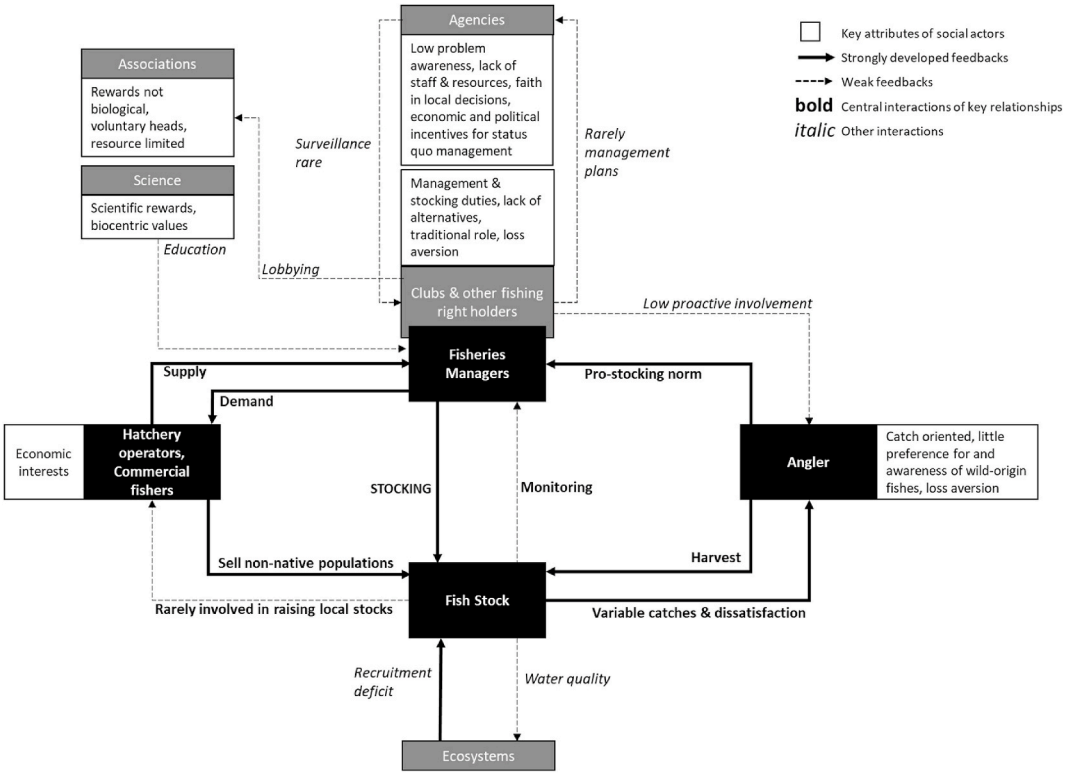

Fig. 3. Major compartments (black and grey boxes) alongside key attributes (white boxes) of each of the social actors as well as key feedbacks (arrows along with key narrative characteristic of the quality of the feedback) in German recreational fisheries involved in stocking. Key actors and feedbacks are in black boxes, less central ones in grey boxes. Strongly developed feedbacks are in bold lines, weak or absent links are in dashed arrows. The situation portrayed is prototypical and inferred from models, quantitative surveys of decision-makers and anglers and qualitative information.

stocking on the length or weight of the harvestable adult fish and stock abundance. Linear thought pattern assumes that increasing the stocking rate will inevitably boost stock sizes and thus future catch rates (von Lindern & Mosler, 2014; Gray et al., 2015; Aminpour et al., 2020). Accordingly, many anglers tend to associate the opportunity to catch fish with the investment of resources into stocking (see also Sass et al., 2017). Additionally, memorizing past catch numbers and expecting similar outcomes in the future may further reinforce the belief in stocking as a suitable management tool (van Poorten et al., 2011). Psychological research has found that particularly memorable events (e.g., high catches) tend to be memorized through the so-called positivity effect, which may in turn become a new benchmark against which to judge future catch rates (so-called shifting baseline syndrome, van Poorten et al., 2011). Given strong interannual variation in catch in line with natural variation in year class strength, many anglers therefore tend to be dissatisfied with their catches (Arlinghaus, 2004; Sass et al., 2017; Birdsong et al., 2021). As anglers in Germany pay membership fees to their clubs and have their say in club activities, they are inclined to expect that their money is reinvested in a way that enhances their membership experience, which translates into restoration, maintenance, and eventually increase of stocks and catch rates. In the mental models of many anglers, stocking seems to be an easy fix when catch rates are declining or too low (Loomis & Fix, 1998, Jackson et al., 2004; von Lindern & Mosler, 2014, Sass et al., 2017). This perspective is fueled by the well expressed functional belief among German anglers that stocking is generally successful in boosting stock sizes (Fig. 4), which agrees with perceptions held by anglers elsewhere (von Lindern & Mosler, 2014; Sass et al., 2017).

3.4. Angler-angler interactions

The catch of anglers is usually unequally distributed with the minority of the anglers, typically the more skilled ones (Monk & Arlinghaus, 2018) and the ones investing more fishing time (Seekell, 2011), catching the highest shares (Baccante, 1995). Angler satisfaction thus constitutes a relative concept that is formed by comparing oneself against the success of others and against certain expectations (e.g., expected catches in the future, see above, van Poorten et al., 2011) that serve as anchor points (Birdsong et al., 2021). This tendency to compare oneself to others is exacerbated by the increasing importance of social media in recreational fisheries, with larger fish receiving more positive attention and interactions ("likes"; Sbragaglia et al., 2020). As many anglers catch little or nothing, among-angler interactions and communication can then reinforce the desire to achieve satisfactory catches via the help of stocking as a short term cure (Sass et al., 2017). Anglers also exchange information about likely causes of catches and possible reasons for a decline. It is then typical to exchange complaints about the manager or the club in general not stocking enough fish or the wrong sizes or species, corroborating social and personal pro-stocking norms and positive attitudes towards stocking as a management action (Fig. 3) (see also Jackson et al., 2004).

There is abundant variation among anglers in the degree of involvement and commitment, which predictably relates to variation in preferences to management, attitudes and beliefs (Bryan, 1977; Arlinghaus & Mehner, 2005, Hunt et al. in press). Bryan (1977) suggested that for freshwater trout anglers in the USA the more avid anglers tend to dislike fish stocking and tend to prefer habitat enhancement or strict harvest limits to support fisheries. For other target species, this assumption has not been confirmed using quantitative surveys in Germany (Arlinghaus & Mehner, 2005; Mäurer, 2020) and the USA (Schroeder et al., 2018). Instead, anglers with higher commitment typically support stocking more than less committed and involved anglers (Fig. 4; Mäurer, 2020). These highly involved anglers also happen to be role models for other anglers (Hahn, 1991) and are possibly those that are more likely to campaign for leading positions in angling clubs (e.g., as a manager), thus potentially reinforcing a club's tendency to engage in stocking in the long term. Anglers taking part in public hearings have also been found to carry different preferences into which species to stock or manage for than the representative angler, sometimes the vocal anglers preferring fisheries based on non-native fishes over native fish management (Hunt et al., 2010).

3.5. Manager - angler

Managers in German angling clubs are usually elected members of the angler constituency. They undergo formal, typically week-long trainings in fisheries management seminars, including principles of fish stocking, and are then entitled to plan and conduct fish stocking in the club waters (Fujitani et al., 2016). The fisheries managers of angling clubs that we surveyed indicated that stocking is conducted for a multitude of reasons involving either social, economic or ecological motivations (Fig. 5). The goals of fish stocking can broadly be classified as either boosting fisheries through stock enhancement or conserving threatened stocks through rebuilding, restoration or supplementary stocking (Lorenzen et al., 2012). Although state-level fisheries laws tend to specify stocking as a measure of last resort (Arlinghaus et al., 2015), strong pro-stocking social norms of the anglers are perceived by the decision makers (Riepe et al., 2017), who in turn respond to these norms by stocking (Fig. 6) to achieve various objectives (Fig. 5). Social norms by anglers may even override functional beliefs of managers that alternatives to stocking (e.g., habitat enhancement) may have a higher

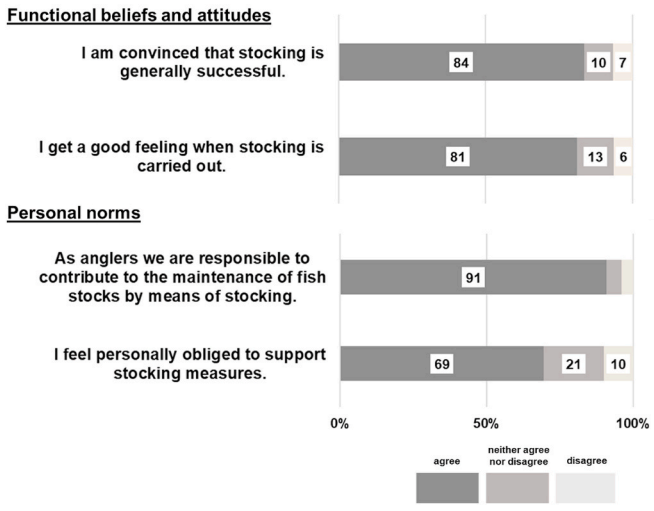

Fig. 4. Stocking-related functional beliefs, attitudes and norms of a random sample of anglers in northwestern Germany (N = 2466).

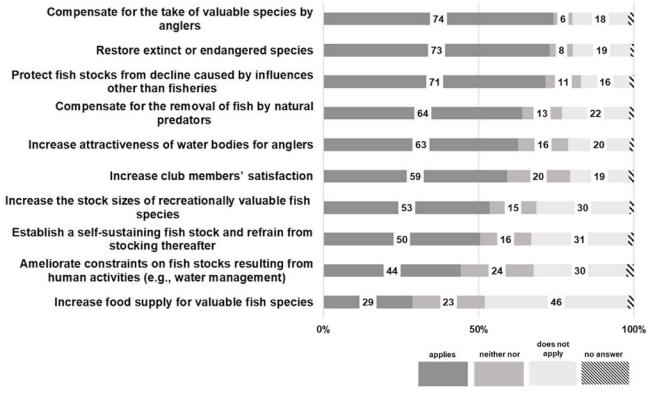

Fig. 5. Fish stocking objectives to be achieved as indicated by 1222 angling club managers in Germany.

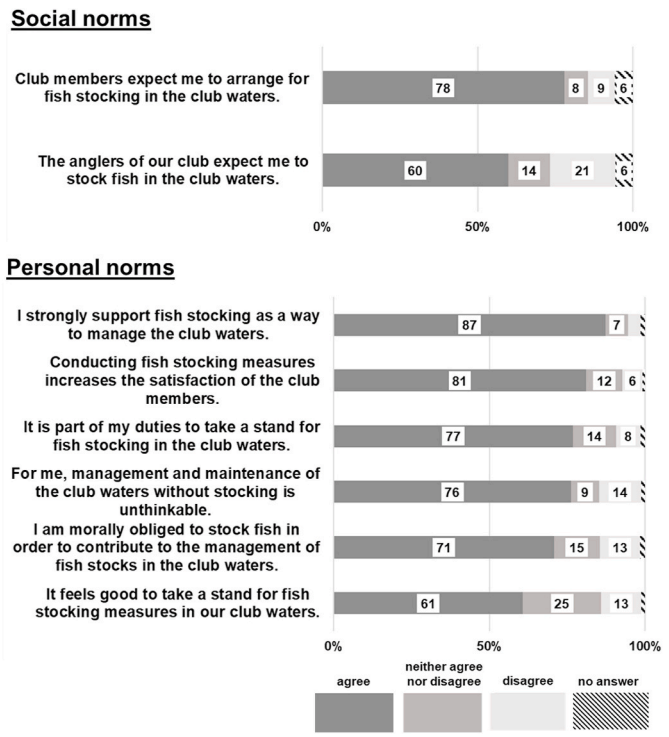

Fig. 6. Social and personal norms among fisheries managers of angling clubs (N = 1222 respondents).

functionality in increasing fish stocks than stocking per se (Fig. 7) (Fujitani et al., 2020). Most likely because the strong social norms that most anglers hold in favour of stocking, changing stocking regimes is judged by managers of angling clubs to be less easily implementable than alternatives to stocking (Fig. 8) (see Sass et al., 2017 for similar situations in the USA). Moreover, managers themselves show strong personal pro-stocking norms (Fig. 6). Yet, ordinary club anglers tend to have an even more positive view on stocking than club managers (Wegener, 2020, p. 207). These findings show that the social embeddedness of stocking in the culture of a local community has a decisive role in motivating stocking and may in some cases override personal convictions held by the decision-maker.

3.6. Manager – fish stock

Many anglers and managers perceive that target species are recruitment-limited (Arlinghaus, 2006) and that stocking could help compensate for recruitment failures (Fig. 5). Clearly, recruitment could more sustainably be promoted by habitat enhancements than stocking (Arlinghaus, Lorenzen, et al., 2016; Sass et al., 2017; FAO 2012). Yet, implementing changes to habitats is logistically more difficult than engaging in stocking and often requires additional nature conservation or hydrological permits. Framed differently: habitat improvements have higher transaction and implementation costs and are thus less implementable relative to stocking for administrative, financial and social reasons (Fig. 8) (for a similar situation in the USA, see Sass et al., 2017). High planning and transaction costs are one reason why people often fall back on the supposedly easier solution to release fish into a water body that needs help, particularly when it is also expected by the club membership to stock. Thus, ultimately social pressure as described in the previous section is an important driver; managers of angling clubs in Germany who feel that the social climate in the club would allow for less stocking as well as the flexibility to try different management options were indeed more likely to perform habitat enhancements (Fujitani et al., 2020).

For animal welfare reasons, most fishes that are stocked by German

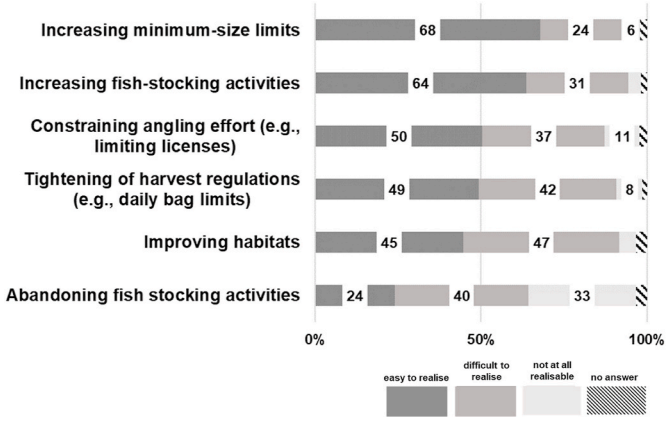

Fig. 8. Ease of implementation of various management tools as perceived by German angling club managers (1.222 respondents).

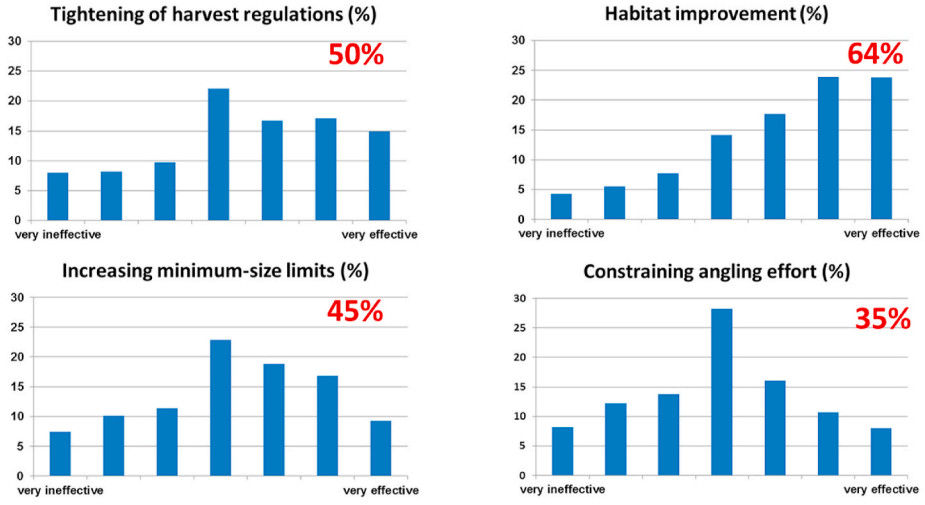

Fig. 7. Functional beliefs about the relative effectiveness of four alternatives to stocking relative to stocking in improving recreational fisheries as perceived by 1222 angling club managers in Germany. The red percentages show the relative frequencies of people perceiving the alternatives to stocking to be functionally superior to stocking. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

angling clubs are not marked, and hence clubs cannot easily learn whether the introduced fish elevated stocks or vanished by falling victim to density-dependent mortality and predation (Lorenzen, 2005). Thus, the systematic monitoring of local fish abundance is practically absent in German recreational fisheries whose main monitoring tools are voluntary landing log books filled by club members. Given a focus on reported fish larger than harvest length and the lack of effort information, these data do not indicate whether natural recruitment has been occurring or not and whether stocks have increased or not in response to stocking (to be indexed by catch per unit effort), which is a decisive decision-node for stocking in strict scientific terms (Lorenzen, 2005; Arlinghaus, Pagel, et al., 2016; Sass et al., 2017). Importantly, animal welfare law prohibits the tagging of fish by angling clubs because any tagging requires animal experimentation permission, which demands writing complex proposals and having passed animal experimentation training that rarely any member of an angling club has. Therefore, the main opportunity to learn from past stocking by observing recapture rates of stocked vs. wild fish is rendered (largely) impossible in the German system. This strongly reduces the manager's abilities to acquire robust ecological knowledge from past stocking practices, fostering path dependencies and stocking legacies (Klein, 1996) – what was done in the past, must help in the future or at least should not be harmful and will perhaps be a safety net to deal with natural variation in recruitment. In addition, most educational material on fisheries management in Germany continues to emphasize stocking as an important form of management (Baer et al., 2007; Mattern, 2015), at least in freshwater fisheries, further creating path dependencies.

3.7. Manager – hatchery operators

The penetration of networks among local fisheries managers in angling clubs and independent scientists is very low (Fig. 9). Only the largest angler associations have biologists in their staff that have some form of formal university training in fisheries science (Daedlow et al., 2011). Most local angling clubs lack such staff and typically do not have the resources to hire scientific consultants. Thus, the most direct source of information about what to stock and at what densities are either personal knowledge, exchange with other angling clubs, or commercial hatchery operators who produce stocking material to be sold to anglers (Fig. 9). Roughly 60% of German angling clubs use advice from commercial operators to inform their stocking (Fig. 9). Although commercial hatchery operators were also identified by some managers as a key source of uncertainty (e.g., due to lack of transparency of the origin of stocking material, Ott, 2015), many clubs follow the advice of hatchery operators. Hatchery operators have direct economic incentives to sell fish for stocking, thus creating conflicts of interest that can fuel the use of stocking. Much of the hatchery-provided fish is traded across biogeographic boundaries (Arlinghaus et al., 2015), creating ample opportunity for genetic mixing but also reducing the likelihood of successful stocking due to maladaptation and stocking stress (Lorenzen et al., 2012). Stocking-related population dynamical models have revealed that in recruiting stocks fish to be stocked must be rather large to generate additive effects on stock size (Lorenzen, 2005; Camp et al., 2017; Johnston et al., 2018). Stocking larval or small fishes in situations with natural recruitment has been found ineffective in empirical studies (Li et al., 1996; Hühn et al., 2014) and models (e.g., Johnston et al., 2018). However, due to the aforementioned lack of monitoring this insight remains cryptic to many, and if the message penetrates it is easy to cognitively dismiss as not applying in the concrete local context. Clearly, stocking can also be highly successful, as put-and-take stocking activities or culture-based stockings show (Lorenzen et al., 2012; Hühn et al., 2014; Amoroso et al., 2017; Johnston et al., 2018). These successes as well as the assumption that many systems rely on stocking are often portrayed to generally hold by hatchery operators, with hatchery operators acting as key advisors that support a pro-stocking view.

In some German states, there are also public hatcheries (e.g., at Lake Constance), similar to those widespread in North America (Halverson, 2008). Some German angling clubs have also built their own hatcheries (Harisson et al., 2018). Public or privately-built hatcheries represent investment of public or private money, which can foster economic and political incentives to be continued (i.e., the sunk-cost fallacy) to justify the creation of hatcheries and the jobs associated with the activity (Barnes & Palmer, 2019). Although these economic incentives are likely of much lower relevance in Germany where most fish that are stocked are generated through commercial culturists or river and lake fisheries, they are likely quite pronounced in open access recreational fisheries, for example in North America (Lorenzen et al., 2010). Overall, economic incentives and cognitive biases that justify the investments can be powerful reasons to continue hatchery activities once they have been built (Lorenzen et al., 2010).

3.8. Manager – scientists

Only about 25% of German angling clubs use scientific information about stocking or have access to it (Fig. 9). Also, managers and anglers tend to contextualize their knowledge in relation to their local ecosystems and their local knowledge. Many thus have issues with believing research results that are developed in systems other than the ones they

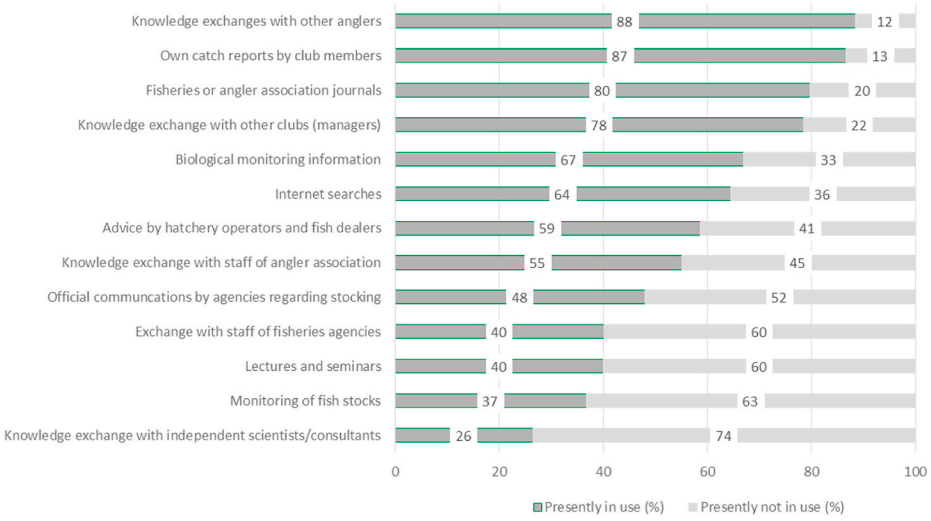

Fig. 9. Use of various information sources about fish stocking by N = 1.222 fisheries managers in angling clubs in Germany.

have under operation. In addition, proper scientific knowledge of stocking outcomes has long been missing in the German fisheries literature, and if it exists it has not filtered through towards local decision making. It is easy to disregard research results as not applying to „my lake", and even if scientific knowledge documented the low effectiveness of many hatchery operations there are powerful cognitive mechanisms to not consider such knowledge in decision-making (Sass et al., 2017). In Germany, research using co-production of knowledge in transdisciplinary settings where managers, anglers and scientists cooperate and jointly conduct stocking experiments with marked fishes have shown how educationally effective these interactions can be (Fujitani et al. 2016, 2017). Yet, such projects are rare. In the absence of robust knowledge, natural stochasticity, pro-stocking social norms and uncertainty create a powerful incentive to perpetuate stocking practices as a safeguard or insurance against natural recruitment bottlenecks (Ott, 2015). This perspective discounts and disregards that in naturally recruiting stocks increasing fractions of non-native genotypes may harm local productivity (Chilcote et al., 2011) – a perspective that is not shared by many anglers and managers in Germany who instead believe that novel genes can create a „refreshment of blood" and thus produce heterosis through hybrid vigour. There is limited evidence for this effect under natural conditions, yet the perspective is widespread among many anglers and managers in angling clubs.

3.9. Manager - policy makers

Interactions between policy makers and local angling clubs are traditionally rare because of limitations in staff and resources for surveillance and control (Fig. 3). Moreover, obligations to stock are often legally established in leaseholder plans and many conservation stocking activities (such as restoration of eel, sturgeon, *Acispenser sturio* or salmon, *Salmo salar*) are subsidized by public policy makers, who receive public appreciation to help conserve threatened biodiversity in mass media. Indeed, public support of stocking is high when stocking is conducted for conservation purposes (Kochalski et al., 2019; Wegener, 2020). Public policy makers that support such stocking thus benefit from public attention and at the same time signal to local angling clubs that stocking is the right thing to do. Moreover, as mentioned before there are strong economic incentives to continue stocking whenever public money is involved, e.g., for building hatcheries as they generate jobs and income in a region (Barnes & Palmer, 2019). In Germany, there is substantial tension between conservation and fisheries interests with regards to some forms of stocking, e.g., release of common carp, *Cyprinus carpio*, for supporting recreational fisheries because abundant carp stocks are often believed to decrease water quality (Waterstraat, 2002, Weber & Brown, 2009, Skeate et al., 2021) or the fear that recreational fisheries systematically stock non-native fishes (Hickley & Chare, 2004). Some conservationists go so far as to accuse stocking to be a legally inacceptable intervention into nature (Waterstraat, 2002). Confronted with such strong positions, public fisheries policy makers often become defensive and defend or at least not actively interfere with local actions by fisheries stakeholders. One blunt reason is that commercial hatchery operators are beneficiaries of the system, and many fisheries officials prefer to protect the jobs and businesses of the fisheries sector. That said, there are examples where state level agencies in Germany engage in education, mostly by producing leaflets and other information sources on engaging in the right forms of stocking (MUNLV NRW 2003). It is unclear how much these actions have changed local thinking and practice, and the general political inertia against changing stocking remains strong (Sass et al., 2017).

A key interaction that might reduce the interest of fisheries policy makers to intervene into the stocking system is financial and further determined by what we call "value-matching". Many small hatcheries in Germany fully or entirely depend financially on demand of fish to be stocked by angling clubs. Therefore, heavily curtailing or even banning stocking would risk losing jobs in the fish culture and fish marketing businesses. In general, fisheries agencies in Germany tend to have staff whose values align with the values and interest of fish culturists and commercial fisheries, creating incentives to keep the liberal engagement in fish stocking without much public surveillance to support the sector as a whole (Arlinghaus et al., 2015). Similarly, in open access systems such as the USA, the sunk cost in public hatcheries create incentives to continue the business despite evidence that stocking often fails or is risky to ecosystems (Sass et al., 2017), particularly if there the perception that stocking maintains or increases fishing interest and helps secure agency budgets (Loomis & Fix, 1998). Coupled with general human tendencies to keep the status quo and to engage in stocking as a habit (Klein, 1996), this can further foster political inertia that avoids adapting public policies in relation to fish stocking (Aas et al., 2018).

4. Synthesis and discussion

The analysis uses a multi-method approach based on qualitative and quantitative surveys among stakeholders, involving anglers and local fisheries managers, and triangulating information from the literature. Our analysis overall shows that stocking is considered a panacea that is conducted for multiple reasons in the German angling system, ranging from stock enhancement with the purpose of ensuring angler satisfaction to conservation objectives. Our surveys revealed that fish stocking constitutes the most dominant management tool among German recreational fishing clubs and that the angler and manager support for stocking is exceedingly high. Multiple reasons contribute to this development, many of which result in stabilizing (negative) feedback loops across the entire SES as illustrated in Fig. 3. The brief stylized synthesis cannot give credit to the full complexity of local level decision-making processes, but may serve as a succinct exposé of the most relevant feedback cycles that keep the system locked in a pro-stocking regime, and thus yield the most salient leverage points for system transformation.

In brief, the lynchpin of the self-organized and self-perpetuating stocking system appears to exist in the interactions between three actors operating at local scales – fisheries managers in local angling clubs, anglers as users (harvesters) of the resource who pay for fishing, and hatchery operators who sell fish. Although fisheries managers and policy managers in agencies as well as scientists in independent research bodies operate at a higher organizational level in the German federal states, there is only a tangential role for these actors in local-level stocking decision-making (Fig. 9). The lack of involvement of agency personnel including fisheries scientists, coupled with the weak regulatory feedback associated with private fishing rights has strongly contributed to the emergence of stocking as a local management panacea. In the absence of any fishery-independent monitoring of stocking outcomes, most feedback about current system status reaches local fisheries managers in the club through harvest reports by anglers and regularly through individual complaints by the angling club members (Fig. 9). As a result, the local fishery is not able to assess objective signals of recruitment level and stocking success or failure, preventing learning by local managers and anglers about whether and when stocking is needed and when it fails (for which there is substantial evidence whenever stocking happens on top of locally recruiting fish due to density-dependent population regulation, Li et al., 1996; Hühn et al., 2014; Sass et al., 2017; Johnston et al., 2018). The lack of ability to learn from past actions is the first major feedback cycle that maintains stocking as an action (Fig. 3).

Angling clubs work under the objective of safeguarding sustainable exploitation in line with Federal Nature Conservation and State-Level Inland Fisheries Legislation, with a secondary objective of maximizing club-level membership satisfaction. The general perception among managers and anglers in the clubs is that most lakes and rivers are impacted by anthropogenic habitat loss, predation by fish-eating birds or pressures of human exploitation (Arlinghaus, 2006; Wegener, 2020). Hence, the majority of managers and club members believe that most inland water bodies are in need of supplementary stocking to maintain

species both from a nature conservation perspective and for fisheries catch (Klein, 1996). A long history of stocking in freshwater has created path dependencies and a habitual reliance on stocking relative to other tools (Klein, 1996). Psychologically, the biggest drivers of local managers' decisions to stock are strong personal and social norms that stocking is necessary to maintain fish populations and angling quality and that engaging in stocking is part of the "moral DNA" of the local managers. Also strong functional beliefs that stocking often works and elevates stocks and catches are prevailing, even more so among anglers than managers (Wegener, 2020). Pro-stocking norms are held by anglers and managers (who are usually elected from the club membership and are anglers themselves) and are reinforced by the lack of alternatives that could be as easily implemented as stocking (e.g., habitat management, Sass et al., 2017) and that do not risk social conflicts (e.g., effort controls). Importantly, the decision makers in the club are affected by strong pro-stocking social norms from the club's membership whose satisfaction is largely catch-dependent, reinforcing simple, linear mental models that more stocking means more future catch (Arlinghaus et al., 2014). This is the key second feedback process. Angler satisfaction, however, often widely fluctuates from year to year due to natural stochasticity in stock-recruitment (van Poorten et al., 2011), which further creates an incentive for anglers to call for stocking to increase stability (Sass et al., 2017).

A third key feedback emerges from hatchery operators taking over a key informant role to educate local fisheries managers about which species or sizes to stock and when to engage in stocking. This is a further form of disrupted information flow, where an actor with strong economic incentives to sell fish takes a key informant role, to some degree filling the lack of robust ecological knowledge about whether and when to stock and when to engage in alternatives to stocking. There are strong social and informational networks among club managers and regional hatchery operators. Given the vested economic interest to sell fish for stocking, there is a tendency for hatchery operators to advise club managers to stock regularly. With limited supply of local-origin stocking material tailored to individual watersheds, stocking often happens with foreign stocks and genotypes, fostering large-scale transfers of non-native genotypes across catchments (Arlinghaus et al., 2015; Eschbach et al. 2016, 2021). As there is little preference among German club anglers for wild fishes (Arlinghaus et al., 2014), these large-scale fish transfers across catchments are not a strong source of concern for anglers. Further, because public fisheries agencies tend to protect the economic activities of commercial hatcheries, and legal enforcement of recommendations to rely on local stocking material is rare, there is political inertia to change stocking operations. These interactions do not contribute as much to the entrenchment of stocking as a behavior as the two key feedbacks mentioned above, but they clearly contribute to the magnitude of the environmental impact that stocking can have when done indiscriminately, thereby filling an information void that the lack of formal monitoring of stocked ecosystems has created.

In summary, high pro-stocking norms fostered by the lack of easily implementable alternative management tools and a lack of involvement (due to lack of political will and understaffing) of government agencies and fishery scientists to assist in local stocking decisions lead to a largely self-organized management system that almost exclusively relies on stocking to provide quality fisheries. Loss aversion (Kahneman et al., 1991), i.e., the reluctance to provisionally stop stocking because aversion to a potential loss in catch outweighs desire for potential gains, prevents objective assessment of stocking outcomes and results in maintenance of current practices. The limited ability of managers and anglers to learn whether stocking works (key feedback 1), the strong catch-dependency of satisfaction coupled with simple mental models about stocking functionality among anglers (key feedback 2), and the key informant role of hatchery operators as well as other economic incentives to continue hatchery operations (key feedback 3) collectively fosters the informal institutions, voiced beliefs and social norms of club members that stocking is sorely needed to maintain catches and that stocking is a desired investment of their local angling license fees (Arlinghaus et al., 2015; Sass et al., 2017).

Collectively, various social-psychological mechanisms and lack of ability to monitor outcomes properly in complex ecological systems foster a culture of stocking and the emergence of stocking as a panacea in freshwater fisheries management of Germany. Positively viewed, this is a resource investment decision by civil society, such that one can conclude that, given the right property rights systems, intensive reinvestment into nature can be expected to evolve (and stay) in recreational fisheries systems with private fishing rights (Fujitani et al., 2020). Yet, evidence is accumulating that many stocking events fail to increase stock size (Li et al., 1996; Lorenzen et al., 2012; Hühn et al., 2014; Johnston et al., 2018), while carrying substantial risks for the ecological and genetic integrity of local systems (Laikre et al., 2010; Camp et al., 2017; Amoroso et al., 2017). Moreover, there is an important trade-off among successful stocking in terms of elevating catch and conservation impacts by affecting wild fish through their interactions with stocked fish (Camp et al., 2017; Johnston et al., 2018). Stocking also carries substantial economic costs, specifically if unintended or past release events of non-native fish create expensive eradication efforts (Johnson et al., 2009). It would thus be advisable to manage key feedback cycles, of which we have identified three central to this issue.

All three key feedbacks are related and involve more robust and reliable (i.e., more scientifically defendable) information about stocking – the ability to monitor the success or failure of stocking events, access to more sources of information regarding stocking for angling clubs besides the hatchery operators, resistance to purely economic arguments to continue stocking because a hatchery exists, and success in overcoming linear thinking (more stocked fish equals more caught fish) in the mental models of many anglers. This suggests that ecological information of higher quality that is effectively communicated and accepted by many could allow for more tailored stocking that is economically more efficient and socially and environmentally more sustainable. This is because, while there are serious doubts on the success probability of many stocking events, one should also stress the conditions where stocking generates positive outcomes for fisheries and also for conservation. Therefore, stocking managers and anglers have much to gain from engaging in stocking when the outlooks are positive and using alternatives when the risk of ecological and economic failure is high. Of decisive importance to motivate stocking is the degree of natural recruitment in an ecosystem (Johnston et al., 2018). Under conditions where natural recruitment is small or even absent (e.g., due to habitat constraints), stocking can be an effective and efficient measure to maintain the species in an ecosystem or elevate catch (Johnston et al., 2018). Stocking with larger bodied individuals can also elevate catch in naturally recruiting species (Amoroso et al., 2017; Camp et al., 2017; Johnston et al., 2018). In that way, put-and-take fisheries and other culture-based fisheries can generate substantial benefits to anglers, which are perhaps the conditions where stocking should be continued. On the other hand, stock enhancements on top of natural recruitment should be suspended and re-evaluated critically. Note that our critical view on stocking is not to be seen as a blunt rejection of the practice. Stocking can deliver substantial fisheries benefits when done properly and stocking by angler communities contributes to a self-image of long-term stewardship that society can build on when local users need to be mobilized for environmental action, e.g., for river rehabilitation (Harrison et al., 2018). Proper information about stocking should help the management system to identify the conditions that create "good" stocking outcomes and avoid the "bad" ones effectively. The challenge is how to get angler communities and manager to internalize this knowledge and act accordingly, which we address in the next section.

The outlook described so far and the key feedbacks that keep the fishery systems locked in heavy reliance of stocking were largely derived from a review of the private fishing rights system of Germany. However, as frequently noted in the text, similar mechanisms are in operation in open access recreational fisheries, for example those in North America

where public agencies are key decision-makers of stocking. Although the scientific knowledge base about stocking and the presence of fishery-independent monitoring efforts is likely to be more advanced and readily available compared to Germany, particularly in the USA (Daedlow et al., 2011), there are very similar feedbacks present as discussed here, as stocking is known to continue despite having monitoring information that the practice often fails (Sass et al., 2017). First, although monitoring information on stocking is present in many states of the USA, the information is still invisible to many and not as easily transferred to anglers as for example is the case of wildlife management (Saas et al., 2017). This reduces the information quality of stocking outcomes to anglers. Second, most angler populations, particularly those in freshwater fisheries in the USA, seem to believe that stocking is necessary to maintain catches or perceive stocking as an easy fix for perceived or real stock declines (Jackson et al., 2004; Sass et al., 2017), similar to the situation in Germany. Finally, similar to club-level managers in Germany, public fisheries managers in fisheries agencies in the USA are also strongly affected by public pressure by anglers to re-invest license dollars into stocking (Camp et al., 2013, Jackson et al., 2004). As hatcheries are typically public in the USA, there is also a tendency to justify continuing hatcheries to maintain jobs, and continue to engage in stocking to maintain public income and license sales (Loomis & Fix, 1998). Overall, although the fishing right systems are different, also in the USA stocking has evolved as a panacea and shows very high inertia to change (Sass et al., 2017). Continued reliance on stocking has unintended consequences for many total catch-and-release freshwater fisheries for species such as largemouth bass (*Micropterus salmoides*) as overstocking can lead to density-dependent processes that reduce individual growth rate and diminish the possibility of lakes to generate trophy fish (Sass & Shaw, 2020). A shift to a more habitat oriented fisheries policy was advocated for by Sass et al. (2017), but changing the fisheries management system of the USA appears equally difficult, similar to the situation reviewed in this paper for Germany and other private governance systems.

4.1. *Leveraging a system to change from red loop to green loop feedbacks*

Our case study shares similarities with the green loop-red loop concept introduced by Cumming et al. (2014). Green feedback loops are exemplified by strong feedback signals between local ecosystems and the local human population that relies on the ecological services. By contrast, red loop feedbacks decouple local social-ecological dynamics by introducing feedbacks with distant systems that can keep local SES in an undesirable state, e.g., by reducing the opportunities for learning about local system states (Crona et al., 2016; Dajka et al., 2020). One example is seafood imports which typically distort the feedback quality of local fish abundance and the perception of fish availability by the local population (Crona et al., 2016; Dajka et al., 2020). Continuous stocking with fish produced elsewhere can have a similar effect to seafood imports and move green loop dynamics toward red loop dynamics and eventually into red traps where local environmental quality, or even fishing quality (Sass & Shaw, 2020), may deteriorate due to missing or inappropriate feedbacks that are present. Reliance on stocking disrupts the direct feedback signal from local overharvest to the quality of fishing, by luring managers and anglers into the (largely false) belief that stocking can cure most fish stock declines. Successful stocking can then introduce foreign genotypes and thereby maladapted genes, lead to disease outbreaks, or if successful in terms of survival of stocked fish lead to density-dependent growth that reduces large fish in the fishery (Sass & Shaw, 2020). Stocking may also be economically wasteful by binding public or angler expenditure money in stocking practices as opposed to using it through alternative means or create high economic costs for eradication of non-natives (Johnson et al., 2009). From a social perspective, incentives are cut off to engage into alternatives to combat local overfishing, such as improved harvest constraints or habitat enhancement (Sass et al., 2017). Also, the incentives to engage in proper monitoring are reduced in extreme form to zero because even in the absence of monitoring stocking promises to be an easy solution to keep fish stocks healthy. Breaking the red loop dynamics necessitates identification of leveraging points by managing feedbacks (Biggs et al., 2012), which is possible through detailed SES analysis such as ours (Dajka et al., 2020).

Meadows (1999) discussed the systems-theory concept of leverage points in her seminal essay. Leverage points are points in a complex system where actions can be taken such that small nudges can lead to large or even fundamental shifts in the complex system. However, people tend to identify and tackle 'weak' leverage points, those that are easy to approach and concrete to conceptualize, but do not in fact lead to system change (Meadows, 1999, p. 18). Increased monitoring, ideally relying on fishery-independent information (Hansen et al., 2015) and environmental education, the remedies identified for key feedbacks 1 (lack of robust stocking outcome information) and 3 (undue influence of hatchery operators and other economic feedbacks), may be such weak leverage points, as they do not address key feedback 2, social change in how anglers think and feel about stocking, which together with a few structural constraints (e.g., availability of money and size of the ecosystems that are managed) have strong influence on how managers behave (Riepe et al., 2017; Fujitani et al., 2020). Although changes in feedbacks 1 and 3 would undeniably impact social, economic and environmental sustainability outcomes, nudging these leverage points alone would unlikely lead to lasting changes in the way stocking is carried out and would not fundamentally challenge the belief in stocking as a paradigm and panacea among the wider angling public.

Altering simple parameters (as in changing how stocking is carried out) and information flows (e.g., monitoring, less reliance on hatchery operators), and even regulating certain feedback loops are low on Meadow's list of places to intervene in a system in terms of effectiveness. Instead to foster large shifts through proportionally small activities, Meadows (1999, p. 18) highlights changing the mindset or paradigm of a system, the "goals, power structures, rules, culture", in our case how anglers as club members think about stocking (feedback 2, Jackson et al., 2004). Abson et al. (2017) elaborate on a pathway towards this leverage point by "re-thinking how knowledge is created". Participatory active adaptive management where scientists and fisheries stakeholders co-produce knowledge is one way to achieve this outcome (Fujitani et al., 2017; Solomon et al., 2020). This is a substantial change to current practice where monitoring and management is usually done by scientists either in agencies or in academia. Acceptability of such knowledge among anglers is low and they do not experience the outcome of stocking evaluations personally, preventing experiential knowledge and co-production of understanding. In participatory adaptive management that we advocate for, rather than the scientists dictating the process, the angling stakeholders state their critical uncertainties and co-design a process of experimentation to learn how their actions affect their managed environment (Berkes, 2009; Solomon et al., 2020). Such co-production of knowledge has been found to increase environmental literacy and fundamentally alter the mental models of participants relative to passive form of ecological science information about stocking (Fujitani et al., 2017). Participatory active adaptive management fosters learning by doing that touches upon critical feedbacks 1 and 2 (monitoring of management outcomes and increasing the reality and complexity of anglers' simple linear stocking mental models) and has been experimentally demonstrated to have strong impacts on knowledge, mental models, and even norms, that exceed the effect of information alone (Fujitani et al., 2017). As demonstrated, participatory adaptive management has the potential to touch upon key feedback 2 and render feedback 3 irrelevant as a side-effect, by affecting the culture and social pressures towards stocking in the club, which can then reduce the sensitivity of demand to (mostly) economic arguments from hatcheries. This is because constructivist learning coupled with two-way knowledge exchange and deliberative discussion ideally creates an environment where participants challenge their own mental models and

even their overall goals, rule systems, and (pro-stocking) culture (Renn, 2006; Newig & Fritsch, 2009). This would allow the system to „self-sort" towards a sustainable trajectory (Arlinghaus et al., 2019), rather than being forced onto one by top down activities.

We and others (Solomon et al., 2020) argue that such a participatory learning process is a key way that anglers, managers and scientists together could examine the pro-stocking paradigm and fundamentally transform how they view the system, and thus their own goals and accepted procedures on the ground. For example, a shift in understanding the system could produce a spatially segregated system where stocking is not used as a panacea and bluntly across all systems as currently the case, but it is used in selected, particularly fitting fisheries only while other systems are left untouched or are managed via harvest regulations and habitat enhancement. Such managerial diversity that is tailored to local conditions is key to achieve resilient fisheries (Hansen et al., 2015; Arlinghaus et al., 2019) and could lead to maintaining community structure and food web interactions for a more consistent and economically efficient fishery. This would not necessarily eliminate stocking, but would shift the implicit goal away from stocking as a panacea, to stocking as a selectively applicable tool to be used under pre-defined conditions (Sass et al., 2017), beyond the goal of simply targeting popular species that are desired as catch to supporting native and less desired species for balance in the ecosystem.

5. Conclusions and implications

The various feedback cycles summarized in this paper suggest that the emergence of stocking as a norm should be expected to develop under private property right systems, i.e., we assume the system to become trapped in a stable pro-stocking regime. The very same outcome is likely under open access recreational fisheries (Sass et al., 2017). Under the private fishing rights systems of Germany, factors that affect the intensity of stocking in addition to the feedbacks emphasized above involve the size and type of the ecosystem (more intensive stocking in smaller and artificial ecosystems), budget size and local angler density (more stocking when both are higher), presence of monitoring (less stocking if it is present, see Sass et al., 2017 for different view in the USA), presence of hatcheries within the club, social norms by anglers as perceived by the decision-makers, functional beliefs of the decision-makers that stocking produces additive effects, and the species to be stocked (higher if recruitment of the target species is small) (Fujitani et al., 2020). Riepe et al. (2017) add that stocking practices in angling clubs may be quite robust to change and strongly affected by perceptions of feasibility (similar to Sass et al., 2017) and the general socio-economic conditions of the club. These leverage points involve "the rules of the system" (e.g., incentives, constraints) and "the power to add, change, evolve, or self-organize system structure", which are complex, yet highly effective leverage points (Meadows, 1999, p. 18). Policy makers in Germany and other private property right systems have to decide whether they accept stocking as a panacea, which this paper suggests is rather inevitable under private governance as well as open access governance as the example from the USA suggests (Sass et al., 2017). In fact, policy inertia to alter stocking is strong, which can result from lack of willingness to tackle difficult problems, lack of problem awareness or because of the presence of economic incentives to maintain hatcheries and the resulting jobs, particularly if these were built with public money and if policy makers want to keep conflicts with their constituency low (Harisson et al., 2019). If policy makers want to change the system and move it beyond the „pro-stocking regime", however, they can use the present work and work by Fujitani et al. (2017, 2020) as a starting point for change. This work has identified potential leverage points in structural properties that alter or modify incentives (e.g., money availability, density of users, habitat quality, type of fishing rights, size of the fishery) as well as the psychological and social understanding of stocking as a management tool, including education on how to monitor stocking outcomes. Active adaptive management and the joint execution of stocking experiments where anglers and scientists collaborate can strongly alter personal and social norms as well as functional beliefs about stocking (Fujitani et al., 2017) and are thus recommended practices from our point of view. Top-down bans on stocking will instead fuel intensive conflict that can have strong repercussions for the generally high stewardship norms that anglers have (Harrison et al. 2018, 2019).

The fundamental lesson of this review is that a range of feedbacks, constrained by the governance and the ecological system, can incentivize the evolution of and in turn fixation on stocking as a panacea-like management response. Three key and interdependent feedbacks seem sufficient to achieve this outcome – a disrupted feedback among ecological state and the management action that prevents learning, a static and simple mental model of the system leading to a stabilizing (negative) feedback among catch, satisfaction, and norms expressed towards the manager to stock to maintain catches by anglers, and commercial operators as key informants of managers about when and what to stock or economic incentives to keep hatcheries that were built with public money or are meant to support public goals (e.g., angling participation). Recreational fisheries with continued reliance on stocking can be considered a stable steady state that is very hard to alter given the many stabilizing feedbacks ranging from resource dependent catch expectations to difficulty in monitoring, high uncertainty about stock developments and strong isolation of most angling clubs that lack networks linking them to modern science. Very similar process might be at play in open access fisheries, as recently summarized by Sass et al. (2017). Interdisciplinary inquiry such as the one presented here is needed to understand the key processes, which in turn can help policy makers find ways to steer the system onto desired trajectories. The lessons from our case in fisheries likely generalize to other systems where humans are users and managers of natural resources, like forestry, gardening, agriculture and hunting. The key message is that whenever ecological feedback signals are either absent or distorted by strategic or unconscious disinformation, well-intended investments by civil society into resources will develop and become fashionable, which can only be changed by systematically changing ecological understanding and the culture of management, monitoring and assessment. This is a formidable task, and transdisciplinary inquiry and co-production of knowledge is one leverage point that offers solutions.

CRediT authorship contribution statement

Robert Arlinghaus: Conceptualization, Writing - conceptualized the study, interpreted data and wrote the manuscript. **Carsten Riepe:** Data collection, Writing – analysed data, produced figures and tables and edited the manuscript. **Sebastian Theis:** Data analysis, Writing – analysed data, produced tables and edited the manuscript. **Thilo Pagel:** Data collection, Writing - collected and analysed data, produced figures and edited the manuscript. **Marie Fujitani:** Data analysis, Writing – analysed data, produced figures and tables and edited the manuscript.

Acknowledgements

We thank the Besatzfisch project team and all involved anglers and managers for their time in answering our many questions and the strong multi-year effort in understanding stocking in Germany. Philipp Czapla is thanked for editorial help. We thank the German Federal Ministry for Education and Research (BMBF) for funding of the projects Besatzfisch and Baggersee. Regarding the project Baggersee, we also thank the German Federal Agency for Nature Conservation (BfN) for funds granted by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU; Grant Number: 01LC1320A). We thank the two anonymous reviewers for constructive reviews that greatly improved the paper.

References

Aas, Ø., Cucherousset, J., Fleming, I. A., Wolter, C., Höjesjö, J., Buoro, M., Santoul, F., Johnsson, J. I., Hindar, K., & Arlinghaus, R. (2018). Salmonid stocking in five North Atlantic jurisdictions: Identifying drivers and barriers to policy change. *Aquatic Conservation: Marine and Freshwater Ecosystems, 28*, 1451–1464.

Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., von Wehrden, H., Abernethy, P., Ives, C. D., Jager, N. W., & Lang, D. J. (2017). Leverage points for sustainability transformation. *Ambio, 46*, 30–39.

Aminpour, P., Gray, S. A., Jetter, A. J., Introne, J. E., Singer, A., & Arlinghaus, R. (2020). Wisdom of stakeholder crowds in complex social–ecological systems. *Nature Sustainability, 3*, 191–199.

Amoroso, R. O., Tillotson, M. D., & Hilborn, R. (2017). Measuring the net biological impact of fisheries enhancement: Pink salmon hatcheries can increase yield, but with apparent costs to wild populations. *Canadian Journal of Fisheries and Aquatic Sciences, 74*, 1233–1242.

Arlinghaus, R. (2004). Recreational fisheries in Germany – a social and economic analysis. *Berichte des IGB, 18*.

Arlinghaus, R. (2006). Overcoming human obstacles to conservation of recreational fishery resources, with emphasis on central Europe. *Environmental Conservation, 33*, 46–59.

Arlinghaus, R., Abbott, J. K., Fenichel, E. P., Carpenter, S. R., Hunt, L. M., Alós, J., Klefoth, T., Cooke, S. J., Hilborn, R., Jensen, O. P., Wilberg, M. J., Post, J. R., & Manfredo, M. J. (2019). Opinion: Governing the recreational dimension of global fisheries. *Proceedings of the National Academy of Sciences of the United States of America, 116*, 5209–5213.

Arlinghaus, R., Alós, J., Beardmore, B., Daedlow, K., Dorow, M., Fujitani, M., Hühn, D., Haider, W., Hunt, L. M., Johnson, B. M., Johnston, F. D., Klefoth, T., Matsumura, S., Monk, C. T., Pagel, T., Post, J. R., Rapp, T., Riepe, C., Ward, H., & Wolter, C. (2017). Understanding and managing freshwater recreational fisheries as complex adaptive social-ecological systems. *Reviews in Fisheries Science & Aquaculture, 25*, 1–41.

Arlinghaus, R., Beardmore, B., Riepe, C., Meyerhoff, J., & Pagel, T. (2014). Species-specific preferences of German recreational anglers for freshwater fishing experiences, with emphasis on the intrinsic utilities of fish stocking and wild fishes. *Journal of Fish Biology, 85*, 1843–1867.

Arlinghaus, R., Beardmore, B., Riepe, C., & Pagel, T. (2020). Species-specific preference heterogeneity in German freshwater anglers, with implications for management. *Journal of Outdoor Recreation and Tourism, 32*, 100216.

Arlinghaus, R., Cyrus, E.-M., Eschbach, E., Fujitani, M., Hühn, D., Johnston, F., Pagel, T., & Riepe, C. (2015). Hand in Hand für eine nachhaltige Angelfischerei: Ergebnisse und Empfehlungen aus fünf Jahren praxisorientierter Forschung zu Fischbesatz und seinen Alternativen. *Berichte des IGB, 28*.

Arlinghaus, R., Lorenzen, K., Johnson, B. M., Cooke, S. J., & Cowx, I. G. (2016a). In J. Craig (Ed.), *Management of freshwater fisheries: Addressing habitat, people and fishes* (pp. 557–579). Oxford: Freshwater Fisheries Ecology, Blackwell Science.

Arlinghaus, R., & Mehner, T. (2005). Determinants of management preferences of recreational anglers in Germany: Habitat management versus fish stocking. *Limnologica, 35*, 2–17.

Arlinghaus, R., Pagel, T., Hühn, D., & Rapp, T. (2016b). Einheitsfanganalysen als praxisnahes Hilfsmittel zur Abschätzung der Fischbestandsentwicklung in Binnengewässern. *Fischerei & Fischmarkt in Mecklenburg-Vorpommern, 2*, 30–41.

Baccante, D. (1995). Assessing catch inequality in walleye angling fisheries. *North American Journal of Fisheries Management, 15*, 661–665.

Baer, J., George, V., Hanfland, S., Lemcke, R., Meyer, L., & Zahn, S. (2007). *Gute fachliche Praxis fischereilicher Besatzmaßnahmen* (Vol. 14). Schriftenreihe des Verbandes Deutscher Fischereiverwaltungsbeamter und Fischereiwissenschaftler e.V., Heft.

Barnes, M. E., & Palmer, T. (2019). Economic impact of McNenny state fish hatchery, Spearfish, South Dakota, USA. *Modern Economy, 10*, 1581–1588.

Beardmore, B., Hunt, L. M., Haider, W., Dorow, M., & Arlinghaus, R. (2015). Effectively managing angler satisfaction in recreational fisheries requires understanding the fish species and the anglers. *Canadian Journal of Fisheries and Aquatic Sciences, 72*, 500–513.

Berkes, F. (2009). Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management, 90*, 1692–1702.

Biggs, R., Carpenter, S. R., & Brock, W. A. (2009). Turning back from the brink: Detecting an impending regime shift in time to avert it. *Proceedings of the National Academy of Sciences of the United States of America, 106*, 826–831.

Biggs, R., Schlüter, M., Biggs, D., Bohensky, E. L., BurnSilver, S., Cundill, G., Dakos, V., Daw, T. M., Evans, L. S., Kotschy, K., Leitch, A. M., Meek, C., Quinlan, A., Raudsepp-Hearne, C., Robards, M. D., Schoon, M. L., Schultz, L., & West, P. C. (2012). Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources, 37*, 421–448.

Birdsong, M., Hunt, L. M., & Arlinghaus, R. (2021). Recreational angler satisfaction: What drives it? *Fish and Fisheries, 22*, 682–706.

Bootsma, M. L., Miller, L., Sass, G. G., Euclide, P. T., & Larson, W. A. (2021). The ghosts of propagation past: Haplotype information clarifies the relative influence of stocking history and phylogeographic processes on contemporary population structure of walleye (*Sander vitreus*). *Evolutionary Applications, 14*, 1124–1144.

Brock, W. A., & Carpenter, S. R. (2007). Panaceas and diversification of environmental policy. *Proceedings of the National Academy of Sciences of the United States of America, 104*, 15206–15211.

Bryan, H. (1977). Leisure value systems and recreational specialization: The case of trout fishermen. *Journal of Leisure Research, 9*, 174–187.

Camp, E. V., Kaemingk, M. A., Ahrens, R. N. M., Potts, W. M., Pine, W. E., III, Weyl, O. L. F., & Pope, K. L. (2020). Resilience management for conservation of inland recreational fisheries. *Frontiers in Ecology and Evolution, 7*, 498.

Camp, E. V., Larkin, S. L., Ahrens, R. N. M., & Lorenzen, K. (2017). Trade-offs between socioeconomic and conservation management objectives in stock enhancement of marine recreational fisheries. *Fisheries Research, 186*, 446–459.

Camp, E. V., Lorenzen, K., Ahrens, R. N. M., Barbieri, L., & Leber, K. M. (2013). Potentials and limitations of stock enhancement in marine recreational fisheries systems: An integrative review of Florida's red drum enhancement. *Reviews in Fisheries Science, 21*, 388–402.

Carpenter, S. R., & Brock, W. A. (2004). Spatial complexity, resilience and policy diversity: Fishing on lake-rich landscapes. *Ecology and Society, 9*, 8.

Carpenter, S. R., Brock, W. A., Hansen, G. J. A., Hansen, J. F., Hennessy, J. M., Isermann, D. A., Pedersen, E. J., Perales, K. M., Rypel, A. L., Sass, G. G., Tunney, T. D., & Vander Zanden, M. J. (2017). Defining a safe operating space for inland recreational fisheries. *Fish and Fisheries, 18*, 1150–1160.

Chilcote, M. W., Goodson, K. W., & Falcy, M. R. (2011). Reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish. *Canadian Journal of Fisheries and Aquatic Sciences, 68*, 511–522.

Clark, C. W. (2006). *The worldwide crisis in fisheries: Economic models and human behavior*. Cambridge: Cambridge University Press.

Cooke, S. J., Twardek, W. M., Lennox, R. J., Zolderdo, A. J., Bower, S. D., Gutowsky, L. F. G., Danylchuk, A. J., Arlinghaus, R., & Beard, D. (2018). The nexus of fun and nutrition: Recreational fishing is also about food. *Fish and Fisheries, 19*, 201–224.

Cowx, I. G. (1994). Stocking strategies. *Fisheries Management and Ecology, 1*, 15–30.

Crona, B. I., Daw, T. M., Swartz, W., Norström, A. V., Nyström, M., Thyresson, M., Folke, C., Hentati-Sundberg, J., Österblom, H., Deutsch, L., & Troell, M. (2016). Masked, diluted and drowned out: How global seafood trade weakens signals from marine ecosystems. *Fish and Fisheries, 17*, 1175–1182.

Cumming, G. S., Buerkert, A., Hoffmann, E. M., Schlecht, E., von Cramon- Taubadel, S., & Tscharntke, T. (2014). Implications of agricultural transitions and urbanization for ecosystem services. *Nature, 515*, 50–57.

Daedlow, K., Beard, T. D., Jr., & Arlinghaus, R. (2011). A property rights-based view on management of inland recreational fisheries: Contrasting common and public fishing rights regimes in Germany and the United States. *American Fisheries Society Symposium, 75*, 13–38.

Dajka, J.-C., Woodhead, A. J., Norström, A. V., Graham, N. A. J., Riechers, M., & Nyström, M. (2020). Red and green loops help uncover missing feedbacks in a coral reef social–ecological system. *People and Nature, 2*, 608–618.

Davis, A. J. S., & Darling, J. A. (2017). Recreational fishing drives non-native aquatic species richness patterns at a continental scale. *Diversity and Distributions, 23*, 692–702.

Eby, L. A., Roach, W. J., Crowder, L. B., & Stanford, J. A. (2006). Effects of stocking-up freshwater food webs. *Trends in Ecology & Evolution, 21*, 576–584.

Eden, S., & Bear, C. (2011). Reading the river through 'watercraft': Environmental engagement through knowledge and practice in freshwater angling. *Cultural Geographies, 18*, 297–314.

Eschbach, E., Nolte, A., Kohlmann, K., Alós, J., Kersten, P., Schöning, S., Rapp, T., & Arlinghaus, R. (2016). Genetische Vielfalt von Zander- und Hechtpopulationen in Deutschland: Schlussfolgerung für die nachhaltige fischereiliche Hege durch Besatz. *Fischer & Teichwirt, 9*, 327–330.

Eschbach, E., Nolte, A. W., Kohlmann, K., Alós, J., Schöning, S., & Arlinghaus, R. (2021). Genetic population structure of a top predatory fish (northern pike, *Esox lucius*) covaries with anthropogenic alteration of freshwater ecosystems. *Freshwater Biology, 66*, 884–901.

FAO (Food and Agricultural Organization of the United Nations). (2012). *Technical guidelines for responsible fisheries: Recreational fisheries*. Rome: Food and Agricultural Organization of the United Nations.

Fisch, K. M., Kozfkay, C. C., Ivy, J. A., Ryder, O. A., & Waples, R. S. (2015). Fish hatchery genetic management techniques: Integrating theory with implementation. *North American Journal of Aquaculture, 77*, 343–357.

Fujitani, M. L., Fenichel, E. P., Torre, J., & Gerber, L. R. (2018). Synthesizing ecological and human use information to understand and manage coastal change. *Ocean & Coastal Management, 162*, 100–109.

Fujitani, M. L., McFall, A., Randler, C., & Arlinghaus, R. (2016). Efficacy of lecture-based environmental education for biodiversity conservation: A robust controlled field experiment with recreational anglers engaged in self-organized fish stocking. *Journal of Applied Ecology, 53*, 25–33.

Fujitani, M., McFall, A., Randler, C., & Arlinghaus, R. (2017). Participatory adaptive management leads to environmental learning outcomes extending beyond the sphere of science. *Science Advances, 3*, Article e1602516.

Fujitani, M. L., Riepe, C., Pagel, T., Buoro, M., Santoul, F., Lassus, R., Cucherousset, J., & Arlinghaus, R. (2020). Ecological and social constraints are key for voluntary investments into renewable natural resources. *Global Environmental Change, 63*, 102125.

Gray, S., Hilsberg, J., McFall, A., & Arlinghaus, R. (2015). The structure and function of angler mental models about fish population ecology: The influence of specialization and target species. *Journal of Outdoor Recreation and Tourism, 12*, 1–13.

Hahn, J. (1991). Angler specialisation: Measurement of a key sociological concept and implications for fisheries management decisions. In D. Guthrie, J. M. Hoenig, M. Holliday, C. M. Jones, M. J. Mills, S. A. Moberly, K. H. Pollock, & D. R. Talhelm (Eds.), *Proceedings of the American fisheries society symposium* (Vol. 12, pp. 380–389). Bethesda, Maryland: Creel and angler surveys in fisheries management.

Halverson, M. A. (2008). Stocking trends: A quantitative review of governmental fish stocking in the United States, 1931 to 2004. *Fisheries, 33*, 69–75.

Hansen, G. J. A., Gaeta, J. W., Hansen, J. F., & Carpenter, S. R. (2015). Learning to manage and managing to learn: Sustaining freshwater recreational fisheries in a changing environment. *Fisheries, 40*, 56–64.
Harrison, H. L., Kochalski, S., Arlinghaus, R., & Aas, Ø. (2018). "Nature's little helpers": A benefits approach to voluntary cultivation of hatchery fish to support wild Atlantic salmon (*Salmo salar*) populations in Norway, Wales, and Germany. *Fisheries Research, 204*, 348–360.
Harrison, H. L., Kochalski, S., Arlinghaus, R., & Aas, Ø. (2019). 'Do you care about the river?' A critical discourse analysis and lessons for management of social conflict over Atlantic salmon (*Salmo salar*) conservation in the case of voluntary stocking in Wales. *People and Nature, 1*, 507–523.
Hickley, P., & Chare, S. (2004). Fisheries for non-native species in England and Wales: Angling or the environment? *Fisheries Management and Ecology, 11*, 203–212.
Horan, R. D., Fenichel, E. P., Drury, K. L. S., & Lodge, D. M. (2011). Managing ecological thresholds in coupled environmental-human systems. *Proceedings of the National Academy of Sciences of the United States of America, 108*, 7333–7338.
Hühn, D., Lübke, K., Skov, C., & Arlinghaus, R. (2014). Natural recruitment, density-dependent juvenile survival, and the potential for additive effects of stock enhancement: An experimental evaluation of stocking northern pike (*Esox lucius* L.) fry. *Canadian Journal of Fisheries and Aquatic Sciences, 71*, 1508–1519.
Hunt, L. M., Arlinghaus, R., Lester, N., & Kushneriuk, R. (2011). The effects of regional angling effort, angler behavior, and harvesting efficiency on landscape patterns of overfishing. *Ecological Applications, 21*, 2555–2575.
Hunt, L. M., Arlinghaus, R., Scott, D., & Kyle, G. (in press). Diversity of angling: Drivers and implications for fisheries management. In W. S. Neal (Ed.), Angler recruitment, retention, and reactivation: Influencing the future of fisheries and aquatic conservation. American Fisheries Society, Bethesda, Maryland.
Hunt, L. M., Gonder, D., & Haider, W. (2010). Hearing the voices from the silent majority: A comparison of preferred fish stocking outcomes for lake Huron by anglers from representative and convenience samples. *Human Dimensions of Wildlife, 15*, 27–44.
Hunt, L. M., Sutton, S. G., & Arlinghaus, R. (2013). Illustrating the critical role of human dimensions research for understanding and managing recreational fisheries within a social-ecological system framework. *Fisheries Management and Ecology, 20*, 111–124.
Jackson, J. R., Boxrucker, J. C., & Willis, D. W. (2004). Trends in agency use of propagated fishes as a management tool in inland fisheries. In M. J. Nickum, P. M Mazik, J. G. Nickum, & D. D. MacKinlay (Eds.), *Propagated fish in resource management* (Vol. 44, pp. 121–138). Bethesda, MD: American Fisheries Society, Symposium.
Johnson, B. M., Arlinghaus, R., & Martinez, P. (2009). Are we doing all we can to stem the tide of illegal fish stocking? *Fisheries, 34*, 389–394.
Johnston, F. D., Allen, M. S., Beardmore, B., Riepe, C., Pagel, T., Hühn, D., & Arlinghaus, R. (2018). How ecological processes shape the outcomes of stock enhancement and harvest regulations in recreational fisheries. *Ecological Applications, 28*, 2033–2054.
Kahneman, D., Knetsch, J. L., & Thaler, R. H. (1991). The endowment effect, loss aversion, and status quo bias. *The Journal of Economic Perspectives, 5*, 193–206.
Klein, M. (1996). Fischbesatz: Gewohnheitsübung, Hegemaßnahme oder Garant zur Ertragssteigerung? *Fischer & Teichwirt, 47*, 152–156.
Kochalski, S., Riepe, C., Fujitani, M., Aas, Ø., & Arlinghaus, R. (2019). Public perception of river fish biodiversity in four European countries. *Conservation Biology, 33*, 164–175.
Laikre, L., Schwartz, M. K., Waples, R. S., Ryman, N., & The GeM Working Group. (2010). Compromising genetic diversity in the wild: Unmonitored large-scale release of plants and animals. *Trends in Ecology & Evolution, 25*, 520–529.
Lewin, W.-C., Arlinghaus, R., & Mehner, T. (2006). Documented and potential biological impacts of recreational fishing: Insights for management and conservation. *Reviews in Fisheries Science, 14*, 305–367.
Li, J., Cohen, Y., Schupp, D. H., & Adelman, I. R. (1996). Effects of walleye stocking on year class strength. *North American Journal of Fisheries Management, 16*, 840–850.
Loomis, J., & Fix, P. (1998). Testing the importance of fish stocking as a determinant of the demand for fishing licenses and fishing effort in Colorado. *Human Dimensions of Wildlife, 3*, 46–61.
Lorenzen, K. (2005). Population dynamics and potential of fisheries stock enhancement: Practical theory for assessment and policy analysis. *Philosophical Transactions of the Royal Society, 360*, 171–189.
Lorenzen, K. (2014). Managing fisheries enhancements. In G. G. Sass, & M. S. Allen (Eds.), *Foundations of fisheries science* (pp. 649–794). Bethesda, Maryland: American Fisheries Society.
Lorenzen, K., Beveridge, M. C. M., & Mangel, M. (2012). Cultured fish: Integrative biology and management of domestication and interactions with wild fish. *Biological Reviews, 87*, 639–660.
Lorenzen, K., Leber, K. M., & Blankenship, H. L. (2010). Responsible approach to marine stock enhancement: An update. *Reviews in Fisheries Science, 18*, 189–210.
Mattern, J. (2015). *Praxishandbuch Gewässerwart – Hege und Pflege von Gewässern*. Stuttgart: Kosmos.
Mäurer, S. (2020). *Influence of anglers specialization on their attitudes, functional beliefs, norms and behavioral intensions towards fish stocking with implications for management and conservation*. Master Thesis, Institut für Biochemie und Biologie Universität von Potsdam, Leibniz-Institut für Gewässerökologie und Binnenfischerei (IGB) in Berlin.
McGinnis, M. D., & Ostrom, E. (2014). Social-ecological system framework: Initial changes and continuing challenges. *Ecology and Society, 19*, 30.
Meadows, D. (1999). *Leverage points: Places to intervene in a system*. Hartland: The Sustainability Institute.
Miller, L. M., & Kapuscinski, A. R. (2003). Genetic guidelines for hatchery supplementation programs. In E. M. Hallermann (Ed.), *Population genetics: Principles and applications for fisheries scientists* (pp. 329–366). Bethesda, MD: American Fisheries Society.
Monk, C. T., & Arlinghaus, R. (2018). Eurasian perch, *Perca fluviatilis*, spatial behaviour determines vulnerability independent of angler skill in a whole-lake reality mining experiment. *Canadian Journal of Fisheries and Aquatic Sciences, 75*, 417–428.
MUNLV NRW. (2003). *Leitlinie zum Fischbesatz in Nordrhein-Westfalen - Bestandsbewertung - Besatz - Erfolgskontrolle. Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz (MUNLV) und Fischereiverband Nordrhein-Westfalen e. V.* (p. 56). Münster.
Newig, J., & Fritsch, O. (2009). Environmental governance: Participatory, multi-level - and effective? *Environmental Policy and Governance, 19*, 197–214.
Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science, 325*, 419–422.
Ott, E. (2015). *Institutional analysis of fish stocking decision-making in German recreational angling organizations*. Master Thesis (p. 178). Humboldt-Universität zu Berlin/ Leibniz-Institut für Gewässerökologie und Binnenfischerei (IGB) in Berlin.
Pope, K. L., Allen, C. R., & Angeler, D. G. (2014). Fishing for resilience. *Transactions of the American Fisheries Society, 143*, 467–478.
Renn, O. (2006). Participatory processes for designing environmental policies. *Land Use Policy, 23*, 34–43.
Riepe, C., Fujitani, M., Cucherousset, J., Pagel, T., Buoro, M., Santoul, F., Lassus, R., & Arlinghaus, R. (2017). What determines the behavioral intention of local-level fisheries managers to alter fish stocking practices in freshwater recreational fisheries of two European countries? *Fisheries Research, 194*, 173–187.
Sass, G. G., Rypel, A. L., & Stafford, J. D. (2017). Inland fisheries habitat management: Lessons learned from wildlife ecology and a proposal for change. *Fisheries, 42*, 197–209.
Sass, G. G., & Shaw, S. L. (2020). Catch-and-release influences on inland recreational fisheries. *Reviews in Fisheries Science & Aquaculture, 28*, 211–227.
Sbragaglia, V., Correia, R. A., Coco, S., & Arlinghaus, R. (2020). Data mining on YouTube reveals Fisher group-specific harvesting patterns and social engagement in recreational anglers and spearfishers. *ICES Journal of Marine Science, 77*, 2234–2244.
Schroeder, S. A., Fulton, D. C., Altena, E., Baird, H., Dieterman, D., & Jennings, M. (2018). The influence of angler values, involvement, catch orientation, satisfaction, agency trust, and demographics on support for habitat protection and restoration versus stocking in publicly managed waters. *Environmental Management, 62*, 665–677.
Seekell, D. A. (2011). Recreational freshwater angler success is not significantly different from a random catch model. *North American Journal of Fisheries Management, 31*, 203–208.
Skeate, E. R., Perrow, M. R., Tomlinson, M. L., Madgwick, G., Harwood, A. J. P., Ottewell, D., … Winfield, I. J. (2021). Fish stocking for recreational angling is culpable for the poor condition of many English lakes designated for conservation purposes. *Inland Waters*. https://doi.org/10.1080/20442041.2020.1867467
Solomon, C. T., Dassow, C. J., Iwicki, C. M., Jensen, O. P., Jones, S. E., Sass, G. G., Trudeau, A., van Poorten, B. T., & Wittaker, D. (2020). Frontiers in modeling social-ecological dynamics of recreational fisheries: A review and synthesis. *Fish and Fisheries, 21*, 973–991.
Taylor, M. D., Chick, R. C., Lorenzen, K., Agnalt, A. L., Leber, K. M., Blankenship, H. L., Haegen, G. V., & Loneragan, N. R. (2017). Fisheries enhancement and restoration in a changing world. *Fisheries Research, 186*, 407–412.
Tufts, B. L., Holden, J., & DeMille, M. (2015). Benefits arising from sustainable use of North America's fishery resources: Economic and conservation impacts of recreational angling. *International Journal of Environmental Studies, 72*, 850–868.
Van Poorten, B. T., Arlinghaus, R., Daedlow, K., & Haertel-Borer, S. S. (2011). Social-ecological interactions, management panaceas, and the future of wild fish populations. *Proceedings of the National Academy of Sciences of the United States of America, 108*, 12554–12559.
von Lindern, E., & Mosler, H.-J. (2014). Insights into fisheries management practices: Using the theory of planned behavior to explain fish stocking among a sample of swiss anglers. *PLoS One, 9*, Article e115360.
Ward, H. G. M., Allen, M. S., Camp, E. V., Cole, N., Hunt, L. M., Matthias, B., Post, J. R., Wilson, K., & Arlinghaus, R. (2016). Understanding and managing social-ecological feedbacks in spatially structured recreational fisheries: The overlooked behavioral dimension. *Fisheries, 41*, 524–535.
Waterstraat, A. (2002). Fischbesatz in natürlichen Gewässern Deutschlands. *Natur und Landschaft, 77*, 446–454.
Weber, M. J., & Brown, M. L. (2009). Effects of common carp on aquatic ecosystems 80 years after "carp as a dominant": Ecological insights for fisheries management. *Reviews in Fisheries Science, 17*, 524–537.
Wegener, N. (2020). *Die angelfischereiliche Hege aus Sicht von Bevölkerung, Bewirtschaftern und Anglern am Beispiel Niedersachsens: Schlussfolgerungen für die fischereiliche und naturschutzfachliche Bewirtschaftung von Binnengewässern. Master Thesis, Leibniz Universität Hannover*. Institut für Umweltplanung/Leibniz-Institut für Gewässerökologie und Binnenfischerei (IGB) in Berlin.
Weibel, U., & Wolf, J. E. (2002). Nachhaltige Fischerei – Genetische und andere Auswirkungen von Besatzmaßnahmen. *Natur und Landschaft, 77*, 437–445.